Exploring Research through Design in Animal-Computer Interaction

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ABSTRACT

This paper explores Research through Design (RtD) as a potential methodology for developing new interactive experiences for animals. We present an example study from an on-going project and examine whether RtD offers an appropriate framework for developing knowledge in the context of Animal-Computer Interaction, as well as considering how best to document such work. We discuss the design journey we undertook to develop interactive systems for captive elephants and the extent to which RtD has enabled us to explore concept development and documentation of research. As a result of our explorations, we propose that particular aspects of RtD can help ACI researchers gain fresh perspectives on the design of technology-enabled devices for non-human animals. We argue that these methods of working can support the investigation of particular and complex situations where no idiomatic interactions yet exist, where collaborative practice is desirable and where the designed objects themselves offer a conceptual window for future research and development.

Author Keywords

ACI, elephant, interface design, experience design, toys, haptics, making, Research through Design, prototype, sketch, workbook.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Animal-Computer Interaction (ACI) devices are novel artifacts that have come into being as the result of a (usually iterative) design process. It could be argued that these devices embody the design choices made during their development, although when documenting their work, the focus of ACI researchers has often been on the forms of interaction supported by the artifacts, as expressed by the behavior of the animal users, with the designed objects represented as props in a larger story. This is in contrast to the design research community, whose interest lies more with the artifacts that have been designed, while users play an important role as an "audience", experiencing and reacting to something new.

One of the aims of the ACI community has been the development of design methodologies that enable animals to be involved in the design process as active participants and design contributors [25]. ACI researchers have proposed a range of methodological approaches, all of which start with a detailed examination of the end-user, involving research into the behavioural characteristics of the particular species. Many researchers have taken inspiration directly from HCI (Human Computer Interaction) and applied traditional UX (User Experience) design principles to the design of interfaces for non-human animals; others have tried to adapt these methods or develop new ones, as the subsequent examples illustrate.

Lawson et al. [21] have claimed that, because of the communication barriers and power inequalities that exist between humans and other animals, it is not possible to understand and involve animals in the design process. Yet humans are still able to design systems to enhance animal welfare. In their speculative design for a "doggy internet", the authors have attempted to view the opportunities offered by ubiquitous networks and mobile technology from a canine perspective, rather than focus on how a dog owner might see value in networked interactions. For example, rather than the owner monitoring the dog to find out what it is doing, the dog can find out when its owner is approaching, which could remove uncertainty and therefore reduce stress. The manifestation of this idea is an imaginary doggy internet portal that leverages normal dog modes of social interaction, based on capacities such as olfaction in which dogs are superior to humans.

Although the work of Lawson et al. is presented in an ironic manner, it makes some fundamental points and expresses the authors' skepticism about the possibility of designing with animals: so long as the process of designing interactive technology for animals is driven by humans, the outcome can only be anthropocentric; on the other hand, technology that was truly designed by animals would effectively be inaccessible to humans.

From a less skeptical position, Westerlaken and Gualeni state that one of their aims is to prevent designers from inadvertently taking an anthropomorphic attitude, and they specifically include animals as participants in their design process [31]. They argue for a "situated approach" to design, directed at the ACI community – taking Haraway's "becoming with" [16] as an inspirational starting point and promoting playing with animals as a way to achieve some non-verbal mutual understanding. Interspecies communication is one of the goals of the method, which was attempted with pet dogs in order to facilitate their participation in the design of new toys.

Jorgensen and Wirman [18] also highlight play as an interspecies (human and animal) co-creative act that can lead to the development of play objects suitable for non-human animals. They point out that user-centred design relies on shared language and experience, which works for humans, but falls short when the user is a different species. Their research describes playing with orangutans as part of the on-going "Touch" project, explaining that by accepting orangutans as capable, creative agents in an interspecies game, the human designer can gain awareness of an orangutan co-player as they both share an experience that offers the human participant some insight into orangutan behaviour and suggests new possibilities for interactions.

Although interspecies play would be widely accepted as part of companion animal welfare, ethical questions are raised when it is considered in relation to other animals in different contexts, an issue pointed out by Westerlaken and Gualeni [31]. For example, many zoos aim to offer their animals as normal a life as possible, promoting only species-specific wild behaviours, none of which include playing games, or indeed doing any other activities, with humans. On the other hand, it should be noted that play behaviour in zoo-housed animals is widely acknowledged as an indication of good welfare, as it suggests that the animals are relatively free from stress and therefore willing to engage with unknown scenarios [32][6][28].

Welfare and ethics are highlighted in AWAX, a new framework proposed by van der Linden and Zamansky [20]. AWAX represents: Agile development (iteration), Welfare as value, Animal eXperts on board. The authors stress the importance of collaborating with animal behavior experts and of having the animals' welfare as a key design goal.

In the field of Animal Behaviour Science, Dawkins' work on preference testing to determine motivation in animals [8] demonstrated that the study of behaviour could be a valid method for assessing welfare. The benefits of this approach are that it is non-invasive and gives animals an opportunity "to express their own priorities" [19]. Current research on welfare includes sentience and feelings as well as the traditional welfare indicators of physical health and expression of natural behaviours [5][3]. Although it is not possible to observe subjective experiences of animals, researchers have tried to determine what animals want, and therefore how they feel about their situation, using preference, motivation and aversion testing [19]. Preference and motivation testing requires that the animals are allowed some control over their resources and are offered choices; understandably, questions still arise regarding what choices might be appropriate to offer in the first place. How can researchers make the imaginative leap required to devise interesting and enriching artifacts that can be tested with non-human species?

A recent workshop on ACI methodologies [33] concluded that researchers should remain open to all possible ways of provoking novel designs. In this paper, we discuss aspects of the Research through Design (RtD) framework in order to understand whether it is an appropriate methodological approach for designing artifacts that fall under the ACI umbrella - in other words, interactive technologies designed specifically for use by non-human species. In particular, we provide an overview of RtD principles and methodologies followed by a description of one particular design journey, showing how well it fits into a RtD framework.

RESEARCH THROUGH DESIGN

Developed to foster design innovation, Research through Design is a research approach that emphasizes the creation of knowledge through reflective design practice and the making of a series of physical objects, where that knowledge is embodied in the artifacts themselves [13][34], with theory providing context and relevance in the form of annotations on the documented designs. With regard to the type of knowledge expressed through the designed object, Gaver explains that each artifact is the culmination of a series of decisions made by the designer and that the artifact is therefore an exemplification of those choices

Zimmerman et al. [35] provide a critique of RtD as a method for generating knowledge via design research, highlighting the following advantages: (i) it is useful for making inquiries into complex situations; (ii) researchers focus on future (non-existing) designs, leading to (iii) consideration of the associated ethics and potential outcomes. According to Zimmerman et al., what distinguishes RtD from qualitative or quantitative fieldwork is that it: *"focuses on uncovering important relationships between phenomena in the near and speculative future, and not in the present."* Speculative design covers not only future objects (which can potentially be created), but also encompasses future scenarios and ideas, taking inspiration from science fiction (such as the doggy Internet portal mentioned previously).

The creation of real designed objects is one of the goals of design research, and Lowgren [24] claims that *making* is required to effectively explore unknown interaction models - those for which there currently exist no idioms. Making is distinct from designing (an object) because it places emphasis on practical considerations, such as fabrication methods, functionality and, importantly, community involvement. In his definition of making, Lowgren includes “construction, programming and other craft-like activities”, and suggests that traditional prototyping favours black box making because it is focused on the outcome. However, concomitantly with the advent of ubiquitous computing and the increasing availability of physical prototyping components, un-boxing (revealing the mechanisms that provide functionality, rather than concealing them to present only the interface) is becoming increasingly relevant, because the making of the object (how-to) holds interest for people.

There has been a proliferation of websites (such as instructables.com, makezine.com) that offer guidance on how to DIY (Do It Yourself). Locoro et al. [23] explain how ABC (Atoms Bits Convergence) describes the phenomenon of the currently expanding technical making community, and claims that the key features of ABC are: (i) knowledge artifacts, which can be represented in various media; (ii) community, including makerfaires and hack spaces; (iii) marketplaces, such as DIY 3D model emporia as well as the proliferation of online outlets for cheap components; (iv) interaction, in all its forms, and (v) repositories, such as github and other opensource sharing platforms.

There seems to be agreement amongst RtD practitioners that as the creation of prototypes transforms abstract concepts into concrete artifacts, it simultaneously allows the designer to share their ideas, facilitating first to second order knowledge generation [1] – in other words, allowing others to understand and question design choices that have been made through their own experience with the work. Mousette [27] and Buxton [7] both highlight the advantages of making what they call a physical “sketch” – an approximated physical demo – compared with developing a prototype, which is a more fully realised concept. Mousette offers a simplified explanation of a *sketch* as a tangible version of a wireframe (deployed in early design iteration and user testing to offer users a chance to try an interactive demo via an interface). Buxton ascribes the following features to a sketch: evocative, provocative, tentative, non-committal, exploratory and questioning. *Prototypes*, on the other hand, are more refined, they answer questions and describe solutions; they are specific and necessarily didactic, since they present a possible response to a brief that the user must learn how to deploy – if well-designed, the device leverages affordances to teach its user what to do.

For Lim et al. [22], such prototypes are “filters that transverse a design space”, thereby making the possibilities and limitations of the design obvious and measurable. The idea that RtD outputs can be verified in some way is seen as attractive, in order to validate it as a method in line with other methods deployed by the scientific and HCI communities. However, the *measurability* of a design is a somewhat contentious issue, for what metrics can we use? One of the challenges that some researchers have identified with RtD [35] [1] is the apparent current lack of evaluation criteria.

Part of the issue is the *particularity* of RtD outputs, which are often unique, highly specific and context-dependent. Bardzell et al. [1] find this to be problematic, asking whether such designs can ever be legitimized, because their distinct nature means they cannot be used to support a generalized theory. The designs may raise more questions than they answer, and moreover, may not fit easily into a more general body of work, thus making it difficult to draw broader conclusions that contribute to a wider theoretical framework [13].

Gaver, on the other hand, emphasizes the individual and conceptually rich outputs that are generated as a strength of the RtD approach [13]. Indeed, he explicitly contrasts RtD outputs with the kinds of theories generated using a “design patterns” approach that draws general principles from large bodies of work, pointing out that RtD outputs can be the inspiration for wider research projects. He also makes the point that since RtD is a useful method for exploring new problems and offering solutions that are manifestations of ideas, the results are likely to be highly particular and their value context dependent.

Evaluation criteria

Raptis [29] refers to the strings of concepts developed by designers as “provocations” and suggests three criteria that might be applied to all such designs – aesthetic, functional and conceptual. Gaver [13] similarly proposes different types of knowledge that an artifact might be said to express – aesthetic, functional, social, philosophical – with the understanding that these can be described although not directly measured. This analysis provides a possible framework for evaluation and offers guidelines for how the work might be documented.

The *aesthetic* aspect is crucial for Gaver, for whom the form and representation of a design are critical. Raptis describes how aesthetics can be deliberately non-pleasing or unexpected in order to spark interest; for him, the whole point of design provocation is to foster high levels of engagement, addressing the overarching goal of the exercise, which is to somehow challenge received opinion.

The kinds of designs envisaged within RtD are not only tangible objects that we can perceive; they are also interactive. Interaction designers appreciate that their work cannot stand alone, but must be actively experienced by users in order to be validated. While the same could be said of any artistic endeavor (eg. reading literature, listening to music), the interplay between the user and the object is critical in interaction design, which examines the nuances of that exchange. This means that the *functionality* of an object is critical.

For Gaver, the *social* aspect of a design relates to its users – asking who they are and how they interact with the designed object. Some researchers [2] have suggested that we are now in the "fourth wave" of HCI – participatory and sharing interactions between humans. This "wave" is directly connected to the accompanying technology and what it enables – we have moved from mainframe computers, through personal PCs to mobile ubiquitous devices and now have networks and companies set up to handle large amounts of traffic and collect massive amounts of data. There are clearly implications for the social aspects of a design, whether it is part of an IoT (Internet of Things) solution or a stand-alone object that acquires a new community of users.

One way of measuring the success of a design is by determining how well it meets the original brief. RtD projects tend to have broad, ideological aims (*philosophical* aspect) that invite an infinite number of interpretations – e.g. "engage public with electricity use and environment" [14]; "find out how kids would like to communicate remotely" [15]. There is therefore a lot of opportunity to brainstorm and play with ideas. Even if designers generate numerous *concepts*, they will never be able to exhaust the realm of possibilities, because there is no limit to what can be created. When the original brief is so broad in scope, it becomes problematic to judge a particular design because any number of other designs might also have been equally fit for purpose. Yet it is not necessary to pass judgement on a design in order to demonstrate its value as a generator of knowledge; it is possible to assess whether a design has helped the developers come closer to reaching their stated goals, but equally, a novel design can stimulate fresh perspectives and trigger changes in direction. It is therefore important to articulate the strengths of designs and explain the rationale for their development.

Documenting design

Bardzell et al. [1] propose three key aspects to be considered when documenting design research: (i) the medium, which is typically a collection of media, aggregated to form a cohesive expression of a relevant aspect of the design; (ii) performativity, which means that the documentation itself is a call to action - a process consisting of a series of sketched proposals, rather than finished representations; (iii) the documentation, which should at the same time work as a set of resources that enable conceptual knowledge to be shared.

It seems clear that a range of media will express the nature of design work more effectively than text alone. Jonas' comment: "Good design should be able to explain its own emergence" [17] begs the question – how? Gaver [13] stresses the utility and importance of keeping an annotated workbook, showing transitions over time and grounding the work in theory that helps to link it to previous research and established precedents. He suggests that multiple perspectives are revealed through the (visual) presentation of many design examples. Zimmerman et al.[35] also support this method of documentation, stating that designers should show how their perceptions of the problem/ brief have changed over time, and specifically what has triggered the change. Bowers [4] also supports the notion that an annotated portfolio is a constructive and viable method for documenting new designs.

This idea is endorsed and explored by Nick Sousanis in the context of a comic book thesis ("Unflattening" [30]), in which the author demonstrates in a very effective manner "the spatial interplay of sequential and simultaneous" that results from presenting information in a one-page layout and using graphics as well as text to capture the reader's attention and convey complex concepts. He contrasts this form with the linearity of traditional academic writing, claiming that the more holistic approach of the comic offers cognitive benefits for the reader. Dykes et al. [9] develop this point of view to argue for comics as a viable alternative to design notebooks because they have their own idioms allowing the writer to situate text in different ways – e.g. speech bubbles, captions, labels – and that this aids comprehension.

Although his work is strongly graphical, Sousanis uses the terms "seeing" and "visual" to "encompass other ways of making meaning and experiencing the world", making reference to dogs' perceptions as an example of how another species can use different senses and gain knowledge about a parallel universe – one that we inhabit but do not perceive or understand very well. Therefore, if researchers/designers plan to make their ideas accessible, they should explore ways of communicating them using different media and modes.

The rest of this paper explores the usefulness, advantages and limitations of RtD for designing for and with animals, following a specific design journey with elephants.

DESIGN JOURNEY: CASE STUDY

Motivation and development

The motivation for this work was provided by the desire to enrich the experiences of zoo-housed elephants, whose lives lack some of the challenges and choices experienced by their wild counterparts [11]. This is an inevitable by-product of being maintained in captivity, even though zoo staff typically work hard to offer their animals as natural a life as possible.

The project has evolved over several years, starting in 2013 with an investigation into elephant lifestyle and behavior, based on research conducted by professionals in the field. This was followed by a three-month ethnographic study of four captive African elephants at Colchester Zoo and lengthy discussions with elephant experts. We then began to work with an Asian elephant in Wales, making a series of rough interactive prototypes. These were both objects for discussion and practical interventions that allowed us to learn more about the elephant's inclinations and preferred modes of interaction [10]. Additionally, they were responses to two distinct design briefs: (i) to create a playful system that offered cognitive and sensory enrichment to an elephant (our original research question); (ii) to build elephant-friendly shower controls (a tightly defined goal that was requested by the keeper).

At first we attempted some traditional HCI approaches to UX Design, adopting them for another species. We researched our user, created concept sketches (on paper) and shared them with stake-holders to generate interest and obtain feedback. However, some well-known design techniques seemed unrealistic – for example, using a scenario. We had no idea how an elephant might react to an interactive device and it seemed inappropriate to try and tell a story about what the elephant did when she wanted to have a shower, or wanted to play, because no-one has any idea what an elephant is really feeling or thinking at any moment. It seemed like a step too far into the world of fiction and moreover, our experience of discussing elephant enrichment with zoologists and animal behaviourists who had a scientific background persuaded us that a more pragmatic approach would be better for capturing the attention of the animal keepers with whom we hoped to work.

In consequence, we decided to explore our ideas further by taking the designs off the page and conducting some fieldwork. We offered real artifacts to elephants (and their keepers), then made observations. This involved many design iterations, as well as planning and implementing a series of prototypes to be tested in the field. We attempted to follow a participatory design methodology, arguing that observations of elephants using our devices counted as feedback and that therefore the elephants became participants and contributed actively to the design. Yet, in fact, the elephants were unaware of the procedure and were unable to convey their thoughts directly. All responses were filtered through human interpretations (keepers, animal behaviour specialists, designers); even raw data (video footage) has had to be interpreted.

The unique nature of the work (designing an interactive experience for an elephant) meant that documenting the process did not fall neatly into existing frameworks for development. The act of crafting the interactive devices brought to our focus some of the aspects of physical design that are highly relevant when designing for another species. As we worked through design iterations, inventing new objects and then building them, it became apparent that our approach had much in common with Research through Design methodology, as we explain in the following sections.

Relevance of RtD to designing interactive enrichment with elephants

In the earlier discussion of RtD, we highlighted salient features of the framework, many of which can be usefully applied to our research with elephants.

Particularity

For this research, personalization was a key factor. Elephants are not all the same and captive environments are also unique, therefore designing bespoke solutions was a requirement of the project. We were trying to develop something novel and tangible for a mysterious user – one whose physical and cognitive abilities with regard to manufactured interactive interfaces had not yet been mapped, and therefore there existed no interactive idioms on which to base our work. We undertook an ethnographic study in order to understand the lives of captive elephants and their keepers [11], but this was also specific to the elephant population we visited and therefore could not give rise to generalisations regarding captive animals in UK.

Making and sharing

In our project, the transition from concept to physical product (prototype) was challenging, but ultimately rewarding on several levels. The physical devices we produced enabled us to analyse our concepts with more confidence; for example, understanding the criteria to use for making construction choices so that devices would fit securely in specific locations. In addition, the process of working with physical materials provoked a deeper reflection on the nature of the designed artifact; for example, handling wood while considering how an elephant might approach the same task inspired new insights on the shape, texture and size of the design.

In negotiations with elephants and their keepers, we soon realized that having physical products was extremely helpful for the human participants in the design process, who could thus relate to the underlying concepts more easily. They were also able to visualize systems in place when they were presented with objects they could touch and reconfigure themselves. Involving the keepers in the production phase of the prototyping was motivating for them, as they were able to invest their own creativity into the product. In this respect, creating rough prototypes was useful for forging collaborative practice with keepers, which in turn supported our attempts to enable participatory design with their elephants.

Our prototypes needed to be fully functional pieces of equipment for us to discover whether they were suitable for an elephant to use. The technical aspect of the development was facilitated by being able to access resources (libraries, etc.) that were available online in open-source repositories, as well as deploying Arduinos microcontrollers used for rapid prototyping. In this respect, we became part of the *making community*.

It seems that the community (sharing) aspect of this grassroots movement is critical to its growth and popularity, and we acknowledge the support offered through the network of developers prepared to share their methods and problem-solving techniques.

Prototype or sketch?

It could be argued that the early examples of elephant-friendly buttons we developed fall into the sketch category, because they were tentative, exploratory and could be considered a kind of physical sketch. However, we view them as traditional prototypes because they were carefully crafted attempts at viable solutions. Each iteration was a complex blend of microcontroller programming, embedded sensors and hidden actuators, controlled via a specifically designed interface and linked to either a computer system or an electronic output device. When designing with animals, we argue that prototypes are better than sketches because non-human stakeholders don't have the same capabilities of abstraction and projection (imagination) as human stakeholders.

Evaluation criteria

During the research, we identified a subset of goals that we could use to specify each iteration of our design, namely: (i) welfare/enrichment potential, (ii) collaboration (e.g. teamwork and participatory design), (iii) playfulness, (iv) usability (e.g. can an elephant interact with this?), (v) physical manifestation (can we build it? yes we can!), (vi) technical dimension (e.g. do these sensors work?), (vii) education (e.g. dissemination, impact). These goals could be formally assessed for each intervention, which would potentially generate some qualitative and quantitative data.

However, RtD workbook annotation places emphasis on the reasons for making design decisions *before* a prototype is generated, rather than attempting to evaluate the prototype after it has been tested. Clearly, there is a cause and effect chain whereby the reasons are linked to the results of previous iterations. Yet Gaver [13] is dismissive of what he calls "a tendency towards scientism" from the HCI community, whereby research problems are framed in such a way that they offer "scientific proof" of theoretical knowledge – e.g. identify goals, turn into questions, find ways to assess. None-the-less, we have found a goal-oriented approach to be useful for directing our creativity.

Each object we created was a multi-faceted experiment in making and it became a challenge to know how to present the work in a succinct way that would showcase the technical and design elements as well as evaluate the user feedback. Applying RtD design criteria to our research (aesthetic, functional, social, philosophical/conceptual) shows how we might subsequently present our findings and share some of the knowledge we have gained.

Aesthetic

The aesthetic criteria has been applied in our research, as we have gradually modified our designs to accommodate elephants' manifest aesthetic preferences, specifically relating to tactile perception. Thus, we have had to determine a new set of aesthetic criteria, based on elephant modalities of interaction. Over the duration of the interface design aspect of the work, we made many several haptic design decisions in order to enhance the sensory quality (aesthetic experience) of the interface for the elephant users. These included modifications to:

- Shape – initially we offered rounded, organic shapes, but corners and edges seemed to generate as much interest from the elephant and were simpler to manufacture, which was another kind of design constraint.
- Size – controls had to be suitable for an elephant trunk tip to activate and be able to differentiate between different buttons.
- Materials – we used wood and hessian rather than metals, partly due to manufacturing and financial constraints but also because it was familiar and found in natural environment.

Figure 1: Early button prototypes

Figure 2: Vibromotors attached to back of button interface

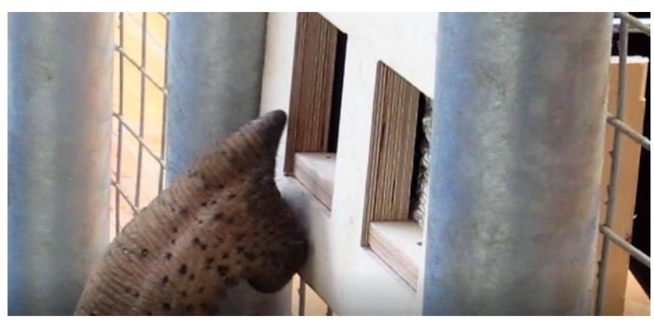

Figure 3: Elephant explores button object

- Plasticity – controls were mostly rigid because we were unable to produce a device that was both safe and flexible.
- Texture and surface detail – ridged surfaces and knitted rope provided tactile interest.
- Kinesthetic feedback – mechanical buttons were not effective (elephants don't naturally push buttons) but to provide trigger feedback we used small vibrating motors

which additionally offered low frequency acoustic feedback that an elephant would be able to hear.

- Position – we made sure the devices were both visible and easily accessible without being easy to destroy; requiring location at specific height with good fixings.

Figure 4: Mounting buttons on fence at Noah's Ark

Figure 5: Elephants investigate radio buttons

Functional

In our case, functionality was a measurable criterion, as well as an interesting technical challenge. We were able to identify small, practical goals – for example, when designing input features for a control device, it was necessary to capture elephant interactions using hidden proximity sensors, which required calibration; testing output included finding ways to trigger different acoustic samples. As explained earlier, developing a fully functional physical artifact helped us to share ideas with other humans. In addition, a physical object was the only possible way we could express our abstract ideas so that elephants might be able to understand the functionality and purpose of the devices we designed.

As we found ourselves working simultaneously with two briefs (a playful system and a shower control), we found that the tension between the two objectives altered the way we tackled the challenges and that the briefs were in fact complementary. The broad aim relating to playful enrichment lent itself to a RtD approach, because we had no idea what kinds of systems might be interesting for an elephant, whereas the clear brief to develop an "elephant shower button" required a more prosaic "usability" approach that assessed the utility of various control systems. The outcome of using the shower device was predetermined. Yet, the open question regarding what elephants find interesting and pleasurable (for our playful system brief) led us to discover more about the elephant's responses to the shower design, and to modify both input and output - the interface so that it was more aesthetically pleasing, and the tactile quality of the water supplied (fine spray rather than jet).

Social

We understand social to encompass several different areas: (i) our investigations with elephants, researching their behaviours and abilities, then attempting to establish their preferences; (ii) collaborations with keepers and animal behaviour experts, which also involved determining their points of view; (iii) sharing our findings with the wider community, including academic colleagues and the aforementioned internet of makers.

Our ethnographic studies confirmed that elephants have different personalities and individual preferences, yet we managed to create some interactive buttons that were usable and seemed to have appeal for different animals – male and female, African and Indian, protected and free contact, in herd-like social structures and alone. For animals maintained in a protected contact (PC) environment, there is always a barrier between the keeper and the animal, whereas in free contact (FC) care, the keeper enters the enclosure and interacts directly with the animal.

In the case where we worked with a female Asian elephant who had free contact with her keepers, she was used to regular interaction with humans, including hand-feeding and washing experiences. Because this elephant is used to responding to keeper requests and her actions are often directed by humans, it was difficult to draw conclusions by observing her in her usual environment, with keepers nearby. Her actions were likely to have been influenced by the keepers' presence. On the other hand, in the FC scenario, the keepers were more relaxed around the elephant, keen to help develop enrichment and full of ideas. Involving them in the building and deployment of the devices helped build good relationships, which facilitated further interventions.

The other test case involved two protected contact male African elephants who were housed together, raising questions about competition for environmental resources. We addressed this issue by duplicating the system so that each elephant had individual access to the same device, although we recognise that this is not a scalable solution.

Video recordings of the two PC elephants show that they were interested in the novel objects as soon as they noticed them (Figure 5). The older, larger male spent more time investigating the radio system; initially both elephants reached for the buttons, but the smaller elephant walked away. This raises questions for future research, relating to elephant social dynamics. For example, would it have made a difference to either elephant if the features were spaced further apart? How big is an elephant's personal space with regard to enrichment experiences? Would they take turns playing with a toy? How likely would they be to share?

Over the time period of the project, one of the challenges we faced was being able to make contact with elephant keepers (and through them, their elephants) in the first place – they are all busy, committed people. Zoos are used to allowing zoology students access to undertake scientific projects, which typically follow a clear format. The exact nature of the intervention is known beforehand, whereas we were attempting to introduce a range of experimental and evolving prototypes. Although the enrichment goals were specified, we did not know the best way to achieve them. We were fortunate to be able to work with an elephant housed in a temple sanctuary rather than a zoo for the initial stages of prototyping, because her keepers were very open to the idea of optimistic inquiry with no fixed agenda. Once a working solution had been identified, we were then in a position to present a physical prototype to zoological establishments and discuss the possibility of undertaking research with their animals.

Our plans for the wider social networks that could be reached through our research are mentioned in the documentation section below.

Conceptual – Philosophical

The rationale for any device intended to be used by an animal inevitably incorporates an ethical dimension, which we briefly discuss here.

Researchers who are part of the ACI community will undoubtedly have differing perspectives on the ethics of designing technologies for animals. As a case in point, North [in 33] has stated: "Build only what they want and need." We know that millions of animals are kept in conditions they neither want nor need, for example at the service of socio-economic systems such as the farming industry. Yet we could strive to improve their existence. As Mancini [26] points out, some ACI researchers might be willing to engage with those systems in order to promote animal welfare. Therefore a shared ethical framework would need to be broad enough to encompass a range of values.

Additionally, we should be sensitive to the fact that devices for humans do not always meet the criteria of being both wanted and needed. Designers for humans are allowed the freedom to propose novel concepts that no-one knew they wanted (because they did not think of them and the artifacts did not already exist) and which clearly were unnecessary for survival or indeed welfare.

The emphasis in RtD on particular, context-specific solutions allows researchers to investigate individual problems in depth. A data-driven scientific approach would require a statistically viable number of captive elephants to test a novel device under same conditions in order to authenticate results; however, RtD justifies the exploration of one elephant's preferences, showing how knowledge obtained in a single case study can inspire and inform subsequent projects, as well as the work being an exemplar of "3 Rs" approach (Replace, Refine, Reduce) to conducting experiments with animals.

The fourth wave of HCI mentioned earlier means that we can enable the sharing of an animal's interactions with a system by setting up technology that captures this information and posts it online, yet this is not a choice made by the animal. Some domesticated animals might choose to share information with us, if it were possible [21] but what reason would they have to do this? One ethical position is that it would have to be a reciprocal arrangement, which gives rise to the thought – perhaps, using technology, we could allow elephants to shape OUR behaviour (as dogs do) in parallel to humans designing systems that an elephant has to learn how to use (thereby incrementally changing its behaviour, albeit in a positive way). It may be that the "fifth wave" of HCI involves an investigation of how other species interact with technology, both widening the net of participation and narrowing our research to focus in detail on the specific characteristics of a particular species and its adaptations.

Dissemination

Since the designs we produce will be improved upon by others, it is therefore vital that we disseminate the knowledge, data and skills acquired during the process. There are now multiple ways to do this, by sharing with different communities and engaging with the public as well as other researchers in the same field.

Our work with elephants has been captured using different media: photographs, video, observational notes, hand-drawn sketches. We have attempted to document the different stages of development, from concept work to physical prototypes, giving rationales for design decisions [10] using a traditional academic paper approach, sharing ideas mainly with the ACI community. We believe that the next stage in this process will be to compile a digital notebook with embedded media elements and to attract a wider audience in order to raise awareness of the potential for developing enrichment for captive elephants. The outputs of the research will be publicly available online as a repository of ideas that animal carers and researchers can use as a starting point for future projects, following the examples of resources offered by such organisations such as Shape of Enrichment [36] and ElephantVoices [27].

LESSONS LEARNED

We believe that many of the attributes of Research through Design can be usefully applied to the design of objects to be used in ACI research. This section focuses on the strengths of RtD for this purpose, based on our own experiences.

Particularity

For ACI designers, it is often the case that early prototypes are developed for a small cohort of users – individual case studies are common before large scale deployment of solutions. However, this means that quantitative feedback may be difficult to obtain. Additionally, there is the issue that captive animals are kept in a wide variety of contexts (environmental, geographical, political, social, cultural etc.) and that individuals can be very different from one another. While it is therefore difficult to offer generalisations that apply to all members of a species, RtD emphasizes how particularity can be an advantage. The design of a single, bespoke solution can offer valuable outputs by generating unexpected knowledge and by inspiring future directions for research.

Perhaps the main weakness of RtD is its strong emphasis on the designed object rather than the user's interactions, whereas in the ACI community, practitioners emphasise interaction design and the user behaviour associated with a device. Nonetheless, we have found that focusing on the development of an interactive object for a specific and unique context has garnered rich qualitative data that relates to the behavioral responses of the animals to the artifacts.

Design choices

As we have discussed, RtD proposes a reflective design methodology whereby the choices made by designers are inherent in the objects that are designed, presupposing that a series of such objects will be developed in order to reveal the evolution of the concept through its manifestations. Reflection is practiced by all designers and iterative prototyping clearly shares some of the features of RtD artifact development. Yet, RtD offers a useful method for exploring the nuances of design choices, some of which may not contribute to a final product, but nevertheless contribute to our knowledge of a complex topic.

We would like to draw attention to parallel events – the choices made by designers that influence the final experience offered to the animals, and the choices made by animals if they are offered a way to express their preferences during the process of development. We believe that these design choices should be paramount in ACI design methodology, suggesting a mode of development that values incomplete solutions as sources of inspiration and knowledge – the creation of physical interactive objects that are ultimately deployed by stake-holders (designers, animal users, carers) as cognitive tools. There seems to be general agreement that a series of rough physical "sketches", evolving over time, has more potential for engaging stake-holder collaboration than a high-fidelity "prototype", which is already a version of a solution, ready to be tested. The less finished the piece of work, the more opportunities there are for others to participate in the design by contributing their own ideas. This flexibility can also be extended to the animal users, so that they have the opportunity to make choices regarding the characteristics of the systems we design for them.

Aesthetics

The aesthetic qualities of an experience differ from species to species, depending on which sensory, cognitive and physical characteristics mediate the animal's perception and interaction with environment. Consumer-driven design for humans places great emphasis on aesthetics, and because humans make the decisions about purchasing animal-related equipment, designers may be tempted to appeal to our sense of aesthetic rather than to the non-human user.

ACI designers typically investigate the relevant interaction modalities used by their target species, yet the subtle variations of those interactions may be overlooked in favour of more pragmatic goals (e.g. "Can she tug it?" v. "How pleasurable is it to tug?"). However, aesthetics have welfare implications, potentially contributing to a more enjoyable experience for the animal [12]. In addition, we have found that focusing on aesthetics has given us insights that have led to interesting and novel design decisions involving the use of different materials.

Making and sharing

ACI often involves the construction of novel, physical interactive devices, in order to meet the physical, sensory and cognitive requirements of different species. Therefore interaction design for animals needs to consider the physicality of the whole object as well as its user interface, and this involves "making" skills.

A key value associated with making a physical object for an animal is that it engages our senses with the object in the way that the target species might be engaged – not as a conceptual artifact but as a real item with physical properties (weight, shape, size, texture, smell etc.) that we experience using touch and smell as well as sight and possibly hearing. As well as provoking design insights, this supports collaboration (e.g. participatory design practice) by making it easier for others to understand and evaluate ideas.

The process of *making* a sequence of physical objects is a fundamental aspect of RtD, underpinning its philosophy of design. In the making community, there is a culture of sharing and helping others remotely. RtD practice encourages the dissemination of work through a wide range of channels, because public engagement is a key factor in the evaluation of an artifact, particularly if the designer's aim is to provoke interest. ACI practitioners could follow this lead by releasing their outputs in different forms. Such an initiative would require aptitude for making and for collaboration - for example, there could be significant interest in videos that showcase novel devices being utilized by their target species; yet a range of technical skills would be required to keep production values high.

Philosophical aspects

In sharing our ideas with the wider community, we inevitably communicate some of the philosophy underlying the research. Therefore it is important that the work is grounded in strong ethical principles that can be explained and justified to a broad range of people.

ACI researchers work in a field that is largely unknown. Although connections between animals and technology have been made for many years, the careful design of novel *interactive* artifacts that support animals' behaviour, whether trained (e.g. tools for working animals) or natural (e.g. enrichment for farmed animals), is a relatively recent topic for investigation. As a consequence, at some stage, much of the research involves speculative designs for future (non-existent) objects. RtD methodology supports the documentation of designs for future objects and scenarios, actively encouraging designers to contemplate the impact of their work.

We have found it helpful to use the RtD framework to support the creative development of our broad aims, while using a goal-oriented approach to focus on the functionality and construction of the designed objects.

CONCLUSION

In many ways, ACI research is a step into the unknown, and as we have observed, Research through Design can help us to explore this. We have described how our project fits into the broad framework/category of RtD, and how it has been important to embrace other methodologies (eg. concept sketches, user-centred design, participatory design) in order to design for a non-human species.

This investigation into RtD for an ACI project has revealed many features of design research that can usefully be applied in the context of designing interactive devices for non-human animals. We have shown how RtD supports the design of particular and context-dependent solutions, and how it can help us explore novel situations where there are no known idioms for interaction - for example how an elephant is able to use a shower control. The provocative aspect of some RtD outputs lends itself to ACI research, which aims to raise awareness of animal welfare as well as investigate how to support animals using technology. The making part of RtD, whereby the designer creates a series of physical manifestations of their ideas in order to both share them with the wider community and facilitate reflective practice, has been a fundamental characteristic of our research.

Finally, we have drawn a set of *general* lessons, based on our *particular* findings, which we have shared with the community in this paper.

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